PRACTICAL OP-AMPs.

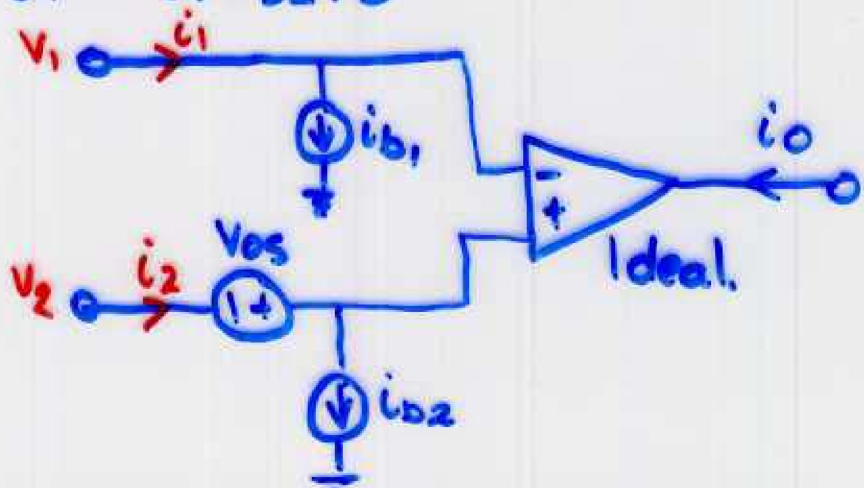
Ideal op amp model

$i_1 = i_2 = 0$
$V_1 = V_2$

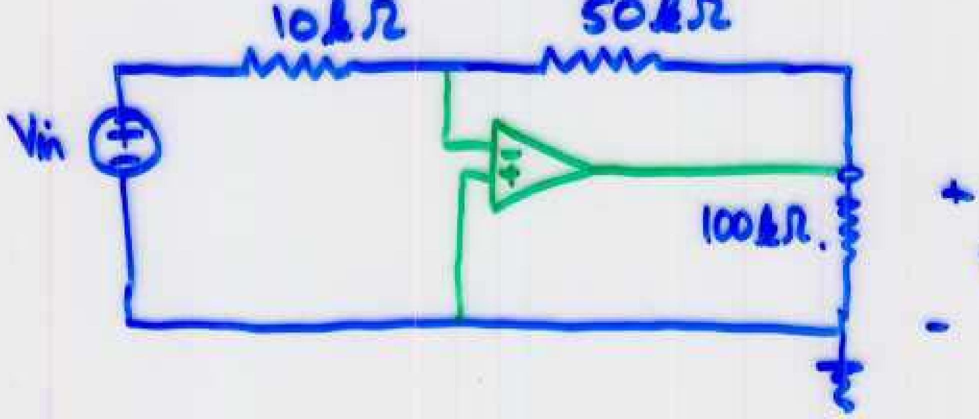
Practical op amps

* Dominant imperfections
  - non zero bias currents
  - non zero input offset voltage
  - finite input resistance
  - non zero output resistance
  - finite voltage gain

* MODEL OF OFFSETS

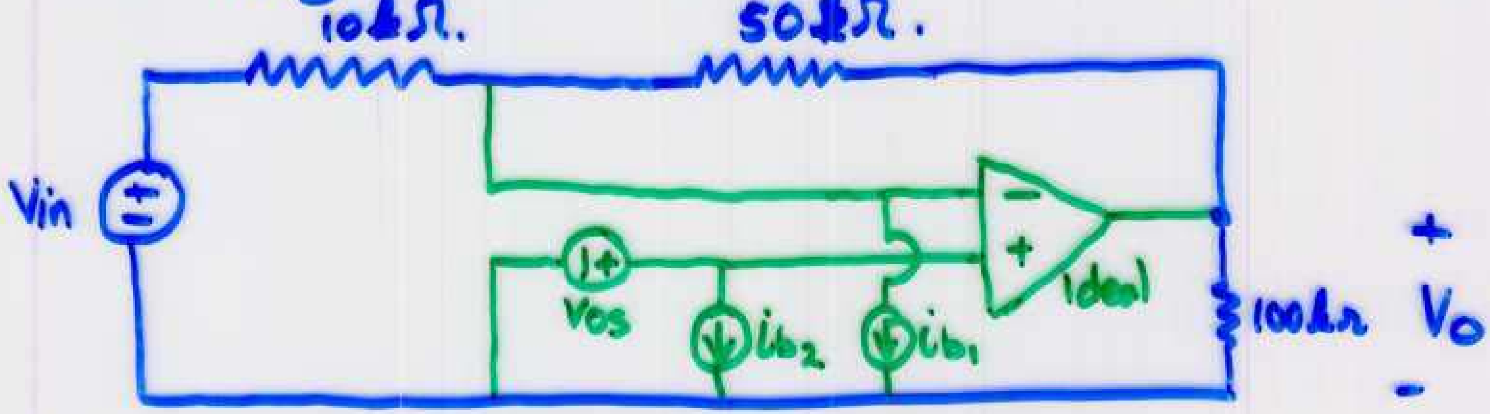


APPLICATION OF THE OFFSETS MODEL



Ideal op-Amp
$\Rightarrow \frac{V_o}{V_{in}} = -5$

Now apply offsets model.

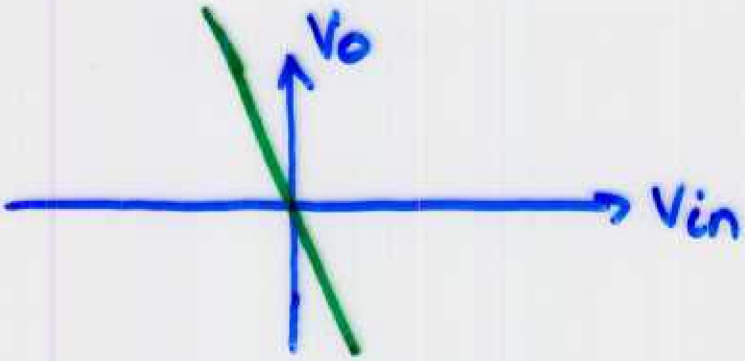


Now find Vo.

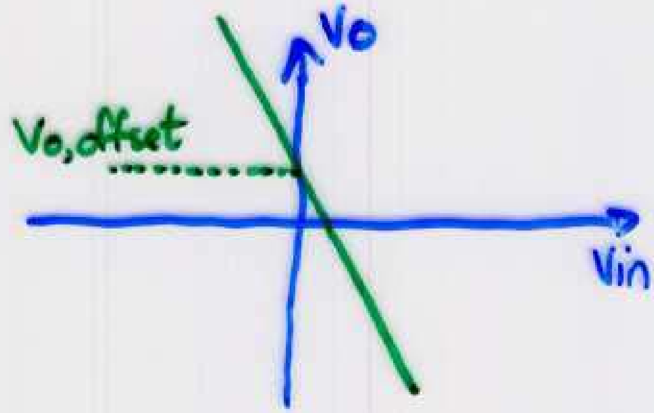
Using Superposition,

$$V_o = -5\,V_{in} + 6\,V_{os} + 50\times10^3\, i_{b1}$$

$$= -5\,V_{in} + V_{o,offset}.$$



Ideal case



offset case.

For this circuit

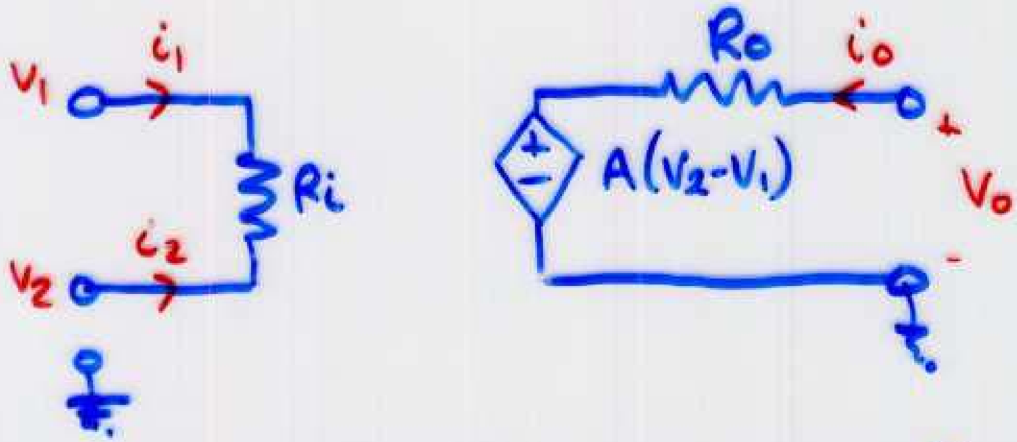
$$V_{o,offset} = 6\, v_{os} + 50\times10^{+3}\, i_{b1}$$

For μA471 chip $|v_{os}| \leq 5\,mV$, $|i_{b1}| \leq 500\,nA$.

$$\Rightarrow |V_{o,offset}| \leq 55\,mV$$

$\Rightarrow$ We can only ignore it if $v_{in} \gg 10\ mV$

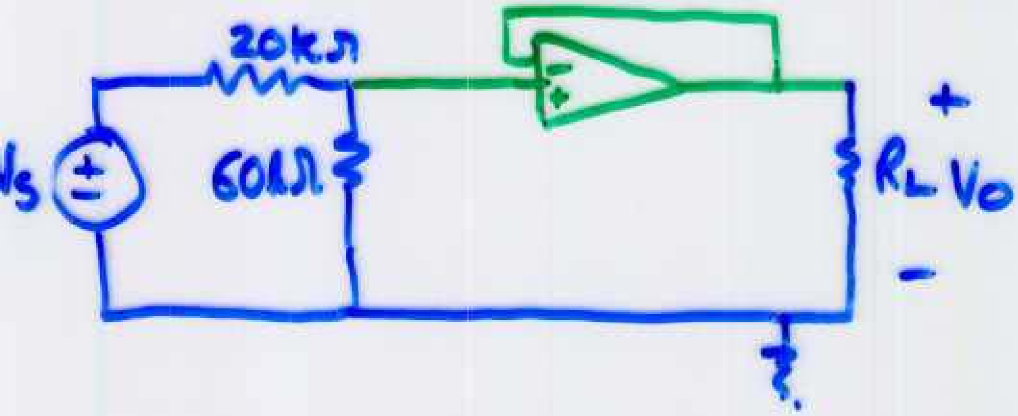
FINITE GAIN MODEL



By Replacing the ideal op amp in the offsets model by the finite gain model, we get a combined model.

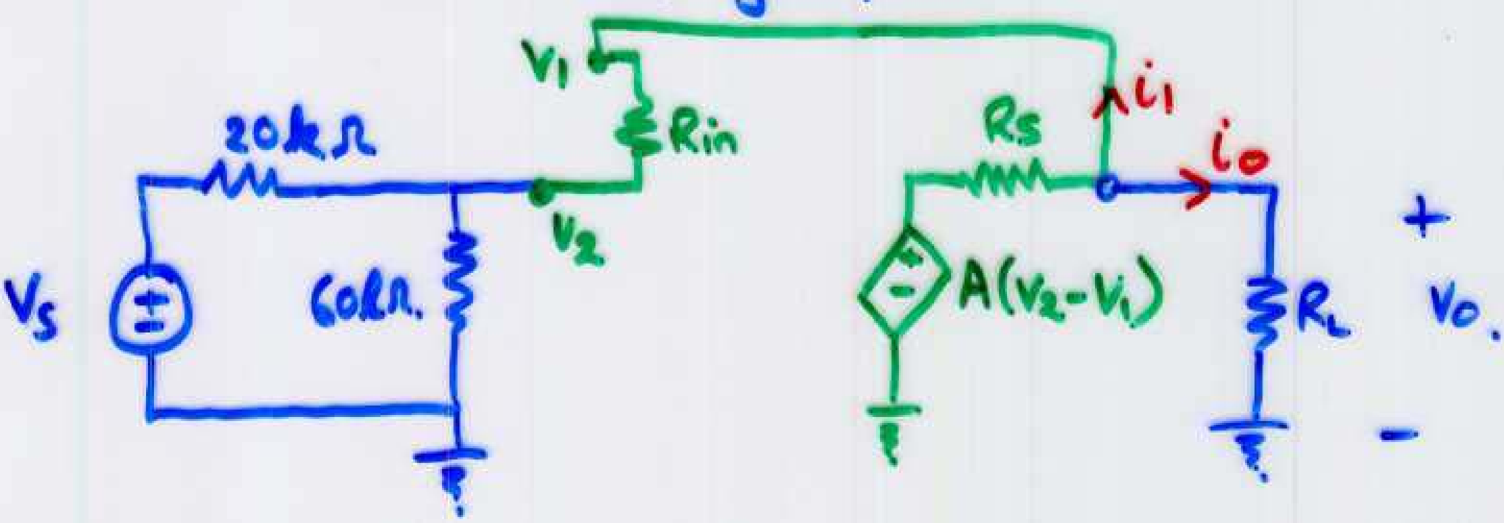
Typical values	(μA741)	[Magnitude bounds]
Bias current, i_{b1}, i_{b2}	80 nA	, $\lvert i_{b1} - i_{b2} \rvert < 20$ nA
offset voltage, v_{os}	1 mV	
Input resistance, R_i	2 MΩ	
Output resistance, R_o	75 Ω	
Differential gain, A	200×10^3 V/V	

APPLICATION OF FINITE GAIN MODEL TO A BUFFER.



if op-amp is linear + ideal, $\frac{V_o}{V_s} = \frac{3}{4}$

What happens if it is linear, has very small offsets, but a finite gain.



Procedure is Node analysis (straight forward)

Algebra is harder than we have seen before.

KCL at output node

$$\textcircled{1}$$

Voltage across Rin $\quad i_1 = \dfrac{v_1 - v_2}{R_{in}}$ $\quad \textcircled{2}$

KCL at node 2

$$\textcircled{3}$$

Short circuit feedback $\quad v_1 = v_o$ $\quad \textcircled{4}$

$\Rightarrow$ 4 equations, 4 unknowns, v_1, v_2, v_o, i_1

$$\textcircled{1}, \textcircled{2}, \textcircled{4} \Rightarrow v_2\left(\frac{A}{R_s} + \frac{1}{R_{in}}\right) = v_o\left(\frac{1}{R_{in}} + \frac{A+1}{R_s} + \frac{1}{R_L}\right)$$

$$\Rightarrow v_2 = v_o\left(\frac{R_L R_s + (A+1) R_{in} R_L + R_{in} R_s}{\cancel{R_{in}}\,\cancel{R_s}\, R_L}\right)\left(\frac{\cancel{R_s}\,\cancel{R_{in}}}{A R_{in} + R_s}\right)$$

$$\textcircled{5}$$

②,③ $\Rightarrow$ $$V_S\left(\frac{1}{20k}+\frac{1}{R_{in}}\right)=V_2\left(\frac{1}{60k}+\frac{1}{20k}+\frac{1}{R_{in}}\right)-\frac{V_O}{R_{in}}$$

Use ⑤

$$V_S\left(\frac{R_{in}+20k}{20k.R_{in}}\right)=V_O\left\{\left[\frac{R_LR_S+(A+1)R_{in}R_L+R_{in}R_S}{R_L(AR_{in}+R_S)}\right]\left[\frac{4R_{in}+60k}{60kR_{in}}\right]-\frac{1}{R_{in}}\right\}$$

$$\Rightarrow V_O=V_S\left(\frac{1+{}^{20k}/_{R_{in}}}{20k}\right)\times\left(\frac{60k\ R_L(AR_{in}+R_S)R_{in}}{(R_LR_S+(A+1)R_LR_{in}+R_SR_{in})(4R_{in}+60k)\ldots\ldots-60kR_L(AR_{in}+R_S)}\right)$$

Now Rewrite.

$$V_O=V_S\left(\frac{1+{}^{20k}/_{R_{in}}}{20k}\right).$$

$$\times\left(\frac{60k\ R_L\left(1+{}^{R_S}/_{AR_{in}}\right)}{4R_L\left(1+\frac{R_S}{AR_{in}}+\frac{1}{AR_{in}}+\frac{R_S}{AR_L}\right)\left(1+\frac{60k}{4R_{in}}\right)-R_L\left(\frac{60k}{R_{in}}+\frac{R_S}{AR_{in}}\right)}\right)$$

For the $\mu A471$ chip

$A = 2\times10^5$, $R_{in} = 2\times10^6$ $R_S = 75\Omega \approx 10^{+2}$

$$\Rightarrow \frac{R_S}{AR_{in}} \sim 10^{-9} \quad , \quad \frac{1}{AR_{in}} \sim 10^{-11}$$

$$\frac{R_S}{AR_L} \sim \frac{10^{-3}}{R_L} \quad , \quad \frac{60k}{AR_{in}} \sim 10^{-2}$$

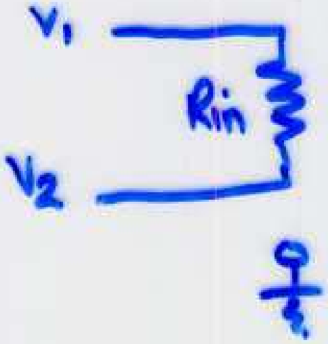
If all these terms become negligible, then.

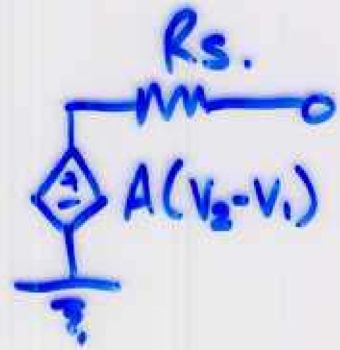
$$V_o \approx V_S \frac{1}{20k} \quad \frac{60k\,R_L}{4R_L}$$

$$= \frac{3V_S}{4}.$$

COMMON MODE REJECTION RATIO.

Previous finite gain model





A better finite gain model has a dependent source of the form.

$$A(v_2-v_1) + A_{cm}\left(\frac{v_2+v_1}{2}\right)$$

v_2-v_1	called	differential voltage.
A	"	differential gain
$(v_2+v_1)/2$	"	common mode voltage
A_{cm}	"	common mode gain

$$CMRR = \frac{A}{A_{cm}}$$

Typical value 30×10^3

Bandwidth.

we have only considered DC circuits

For AC circuits the gain A depends on frequency.

i.e. if $v_2 - v_1 = M \sin\omega t$

then dependent source is

$A(\omega) M \sin\omega t$

This means that you have to pick the right op amp for your frequency range.